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Cobbles at Meridiani Planum, Mars

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Introduction

Along the traverse of the Mars Exploration Rover Opportunity, numerous loose rocks with no obvious physical relationship to outcrop rock have been observed. These rocks are pebble to cobble size according to the Wentworth scale [1] with dimensions typically of several cm or more. Here, we refer to all of these as *cobbles* and we discuss data obtained on the smaller ones; the two largest loose rocks, the iron-nickel meteorite Meridiani Planum (informally known as Heat Shield Rock [2]) and Bounce Rock, a martian basalt [3], are not considered.

To date, about a dozen of these rocks have been analysed with the in-situ instruments, providing information about elemental chemistry (Alpha Particle X-ray spectrometer, APXS), iron mineralogy and oxidation states (Mössbauer spectrometer, MB) and texture (Microscopic Imager, MI) [2, 4]. Miniature Thermal Emission Spectrometer (Mini-TES) spectra are useful for identifying mineralogy and pairing rock types, primarily for measurements collected prior to a planet-encircling dust event beginning around sol 1218. Pancam multispectral analyses are available for a far larger number of cobbles [5].

Jolliff et al. [4] listed working hypotheses for the origin of cobbles at Meridiani Planum:

1. Cobbles are erosional remnants of a layer that once lay above or below the presently exposed outcrops.
2. Cobbles are impact breccias of the outcrop lithology or a mixture of the outcrop lithology and underlying strata.
3. Cobbles are resistant material eroded from the sulfate-rich outcrop, such as rinds or fracture fillings.
4. Some cobbles are fragments of meteorites.
5. Some cobbles are fragments of secondary impact ejecta.

Data analysis

Figure 1 shows cobble APXS data normalized to a typical outcrop target (McKittrick, sol 31). Based on chemical and mineralogical similarities, cobbles fall into three different groups:

(1) Outcrop fragments: Two cobbles, Lion Stone (sol 106) and Russet (sol 381), were identified as fragments of the Meridiani sulfate-rich outcrop. Their chemistry and mineralogy are virtually indistinguishable from outcrop rocks [4, 6].

(2) Meteorite Candidates: In three cobbles, SantaCatarina (sol 1045), Santorini (sol 1741), and Barberton (sol 122), the minerals kamacite and troilite were detected, as well as high Ni contents. The overall chemical composition of these cobbles is most consistent with mesosiderite silicate clasts, and it is possible that they are associated with the impactor that created Victoria crater [2, 7], and possibly others.

(3) Arkansas group cobbles: APXS and MB spectra (Figure 1) obtained on Arkansas (sol 552), Perseverance (sol 554), Antistasi (sol 642), JosephMcCoy (sol 886), and Haiwassee (sol 890) suggest that these cobbles are intermediate between sulfate-rich outcrop and basaltic rock. They are comparably high in Al, P, Ca, and Ti. MB spectra show basaltic and sulfate mineral components. Microscopic images obtained on these cobbles (Figure 2) suggest a brecciated texture. The intermediate composition between sulfate-rich outcrop rock and basaltic rock suggests that these may be the result of an impact-related mixing event. This group could originate from a layer at depth brought to the present location as impact-excavated material, or from some other location and moved laterally as secondary impact ejecta. When their compositions are recalculated on a S-free basis, they are generally basaltic, but different compositionally from Bounce Rock, which itself is secondary ejecta and not locally formed [3].

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Pancam 13 Filter (13F) spectral data (obtained in the range from 430 to 1010 nm) effectively discriminate outcrop-class cobbles from other cobble classes [8]. 13F spectral data from more than 200 loose rocks have been assembled in a database [5]. Spectral parameters obtained from 13F spectra indicate the generic type or crystallinity of ferric minerals [e.g., 9] and may thus be very useful to reveal differences between cobbles. However, dust coatings, viewing geometry and lighting influence 13F spectra and make it difficult to relate Pancam spectral data to the groups identified based on APXS and MB spectra. Mini-TES data have been used to identify a minimum of three additional cobbles that likely belong to the Meteorite candidate group [10].

Conclusions

Based on APXS elemental chemistry and MB iron mineralogy, three different types of cobbles at Meridiani Planum are found. Fragments of the sulfate-rich bedrock are produced by small, local impacts. These are readily distinguished by their chemistry and by Pancam color data. The second group appears to have a meteoritic origin, possibly related to mesosiderites [7]. These are proving to be more common than might be expected from random impact events. The third group is intermediate between sulfate-rich outcrop and basaltic rock, shows a brecciated texture, and may have formed by impact processes. These appear to contain components of the sulfate-rich outcrop rocks and fused soil or other basaltic components.

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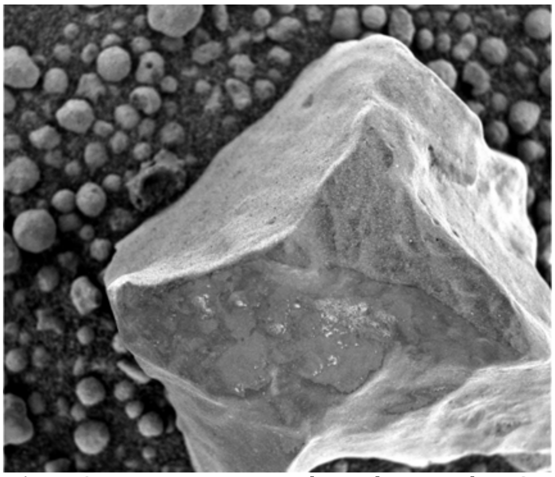

Figure 2: Microscopic image obtained on JosephMcCoy (sol 886), suggesting a clast-in-matrix texture.

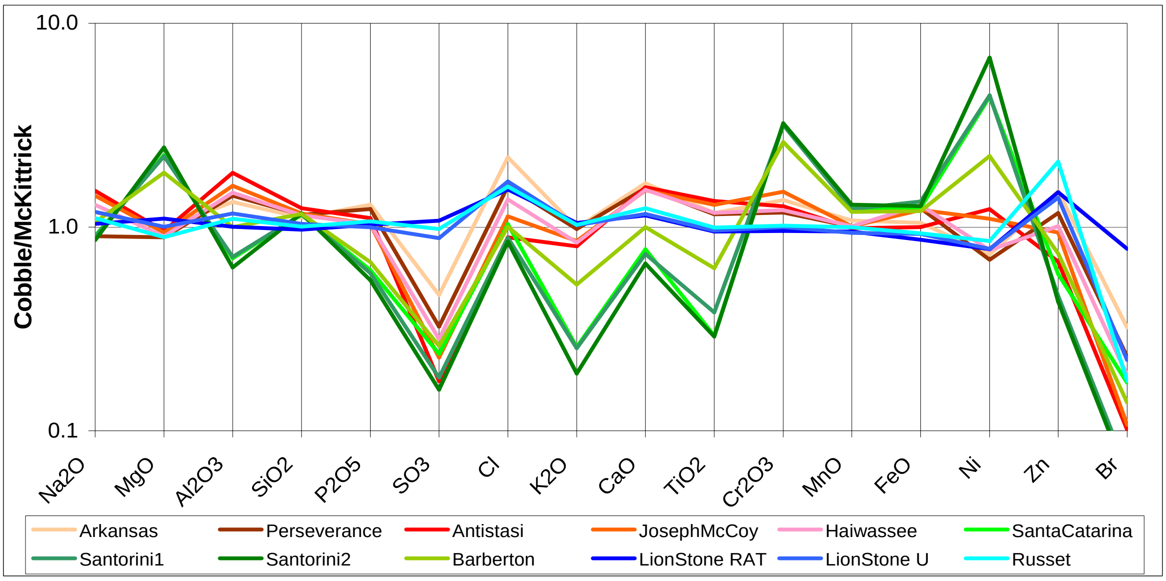

Figure 1: Chemistry of Meridiani cobbles compared to sulfate-rich outcrop rock (McKittrick). Three different groups of cobbles can be distinguished: those similar to outcrop (blue), meteoritic (shades of green), and *Arkansas group* (shades of red).